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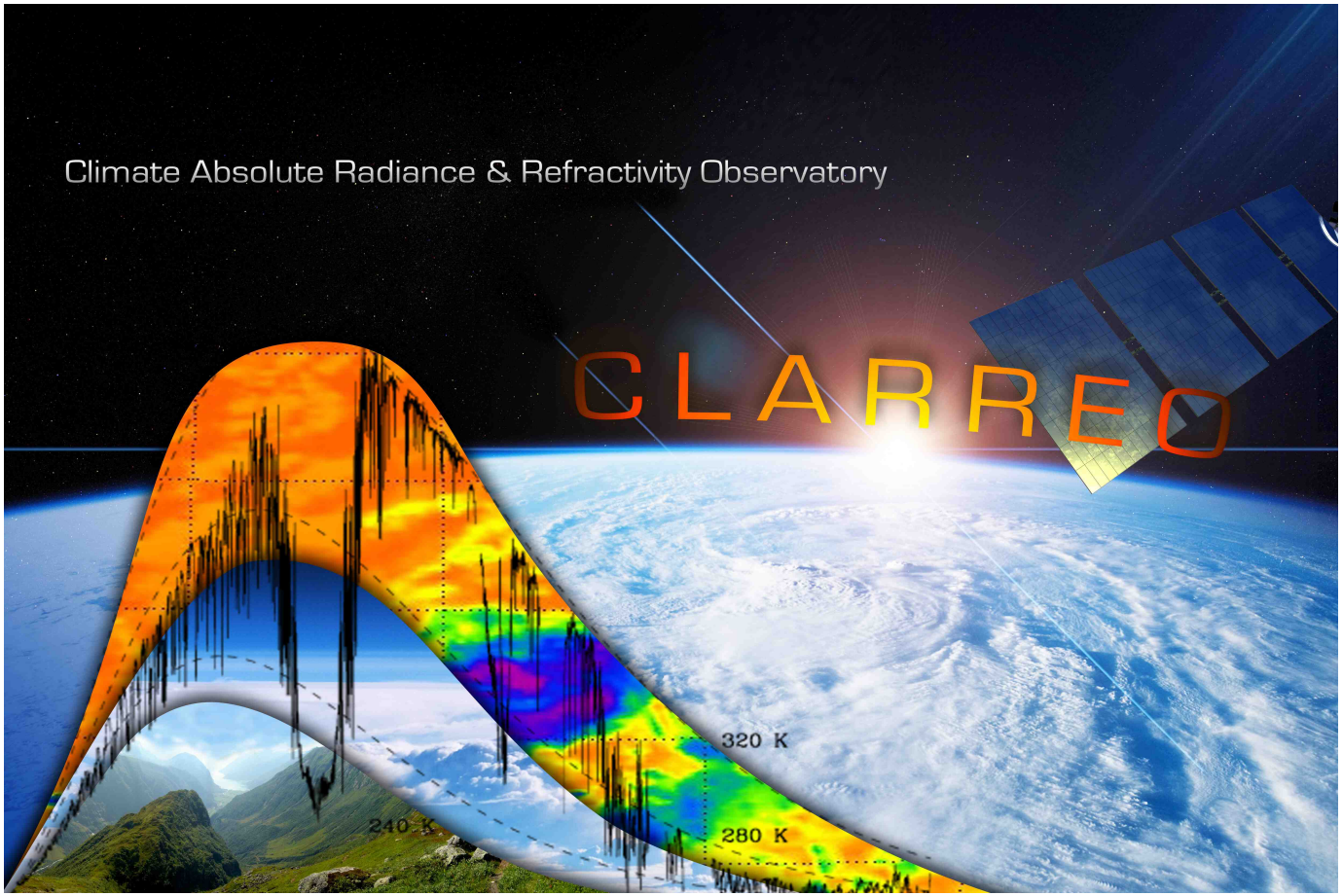
CLARREO Mission Formulation



Stephen Sandford
CLARREO Mission Formulation Manager

2009 Decadal Survey Symposium

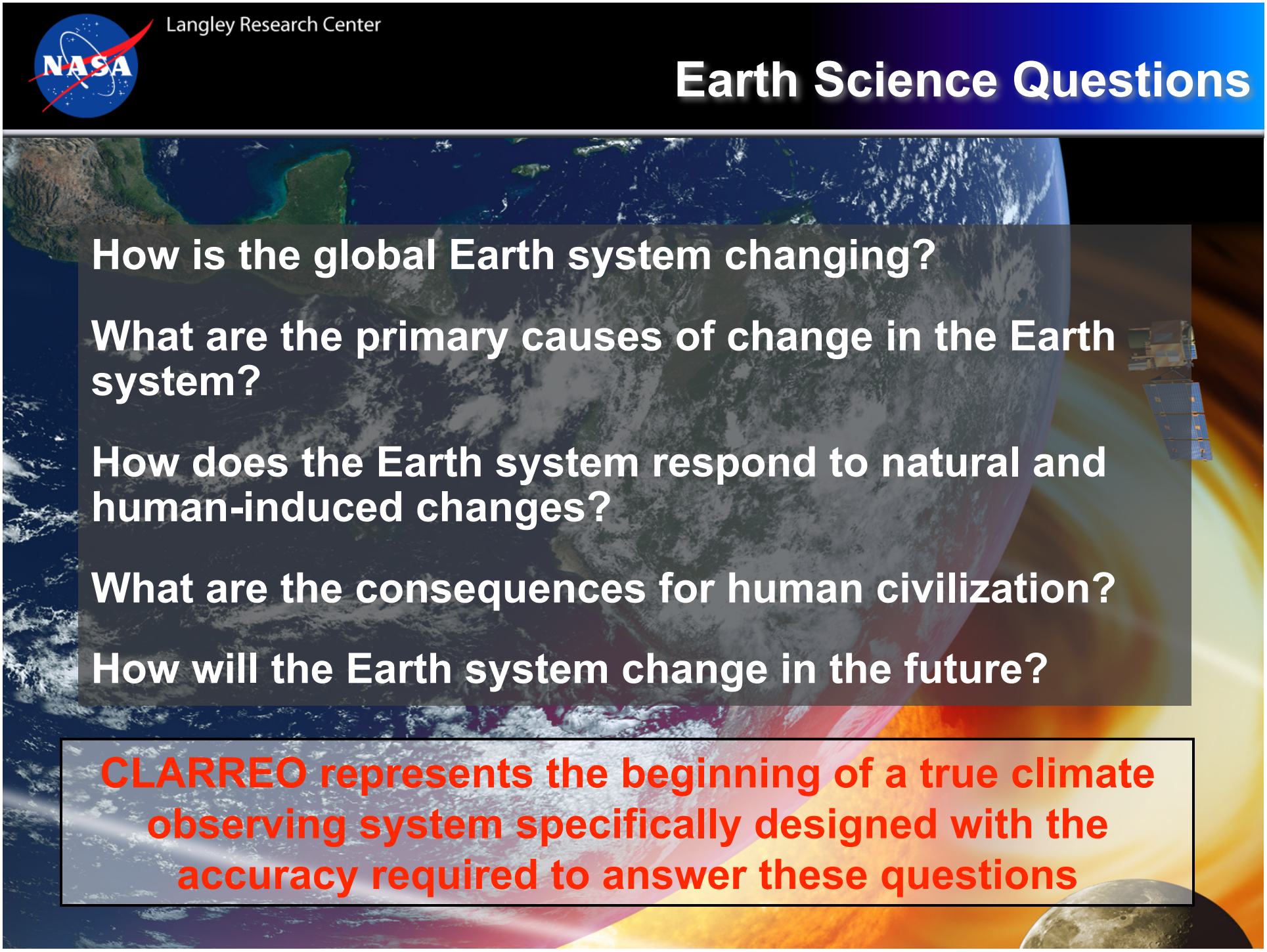
February 11-12, 2009

CLARREO Overview

- Mission formulation is underway at Langley
- The key elements of this mission are understood
- Technology challenges identified: no show stoppers
- Mission design studies began in December 2008
- On track for Mission Concept Review in Fall 2009
- CLARREO can be ready for launch in 2015

What is CLARREO?

- **Climate Absolute Radiance and Refractivity Observatory**
- **CLARREO is a climate-focused mission**
  - Decadal-scale trend detection
  - Improvement and testing of climate predictions
- **Calibration is the foundation of CLARREO**
  - Delivers on-orbit S.I. traceability of measurements
  - Provides calibration of operational and research sensors
- **Joint NASA / NOAA mission**
  - NOAA portion of CLARREO is the continuation of solar irradiance and earth radiation budget observations (TSIS and CERES)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NASA
Earth Science Questions
How is the global Earth system changing?
What are the primary causes of change in the Earth system?
How does the Earth system respond to natural and human-induced changes?
What are the consequences for human civilization?
How will the Earth system change in the future?
CLARREO represents the beginning of a true climate observing system specifically designed with the accuracy required to answer these questions

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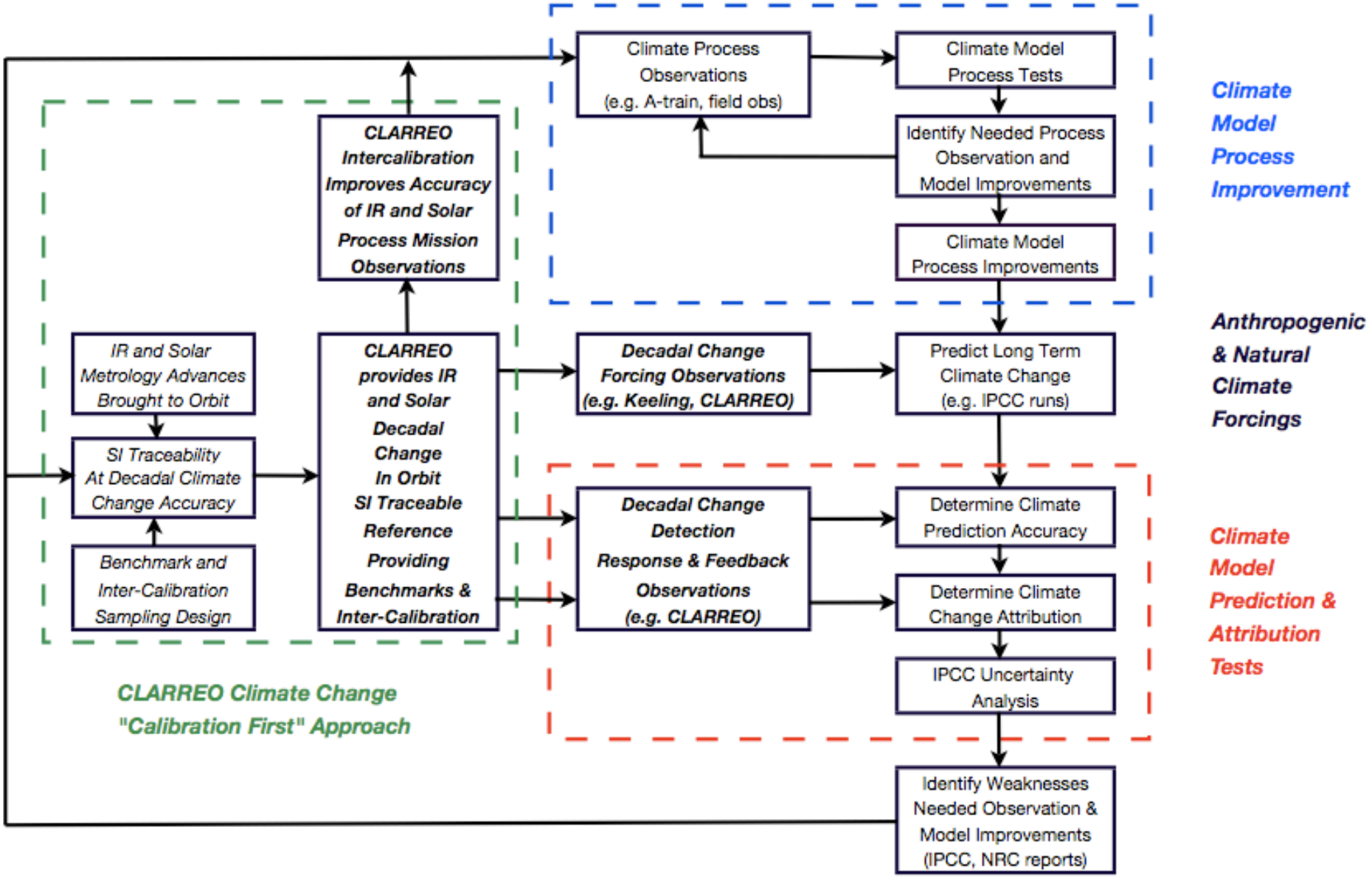
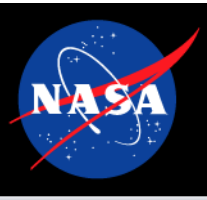
CLARREO's role in the Climate Observing / Modeling System



How does CLARREO Deliver?

CLARREO provides:

- **SI traceable calibration of its observations at the required accuracy to detect decadal-scale climate change in key climate variables**
- **Wavelength/space/time/angle sampling sufficient to sampling noise (random) and alias (changing bias) to a level well below that of decadal-scale climate change**
- **Observations sufficient to determine changes in climate variable shown by climate models to be key to understanding past and future climate change**
- **Select orbits and instrument pointing, spectral resolution, spectral coverage in order to assure that CLARREO can calibrate other solar & infrared sensors in LEO and GEO orbits**



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Mission Science Study Approach

- **Mission Science Study Goals**
  - **Clarify mission requirements to ensure climate science and NASA's performance objectives are met, future costs are contained, and delays are minimized.**
  - **Respond to several key areas of concern**
    - **Clearer definition of science requirements**
    - **Greater involvement of the climate modeling community**
    - **More rigorous and detailed analysis of projected costs**
    - **Deeper understanding of the trade space of science value/cost**

- **Science studies are based on key questions derived from community input**
  - **The mission objectives are defined by the Decadal Survey**
  - **Two Community Workshops have been held to clarify objectives**

- **The Mission Science Study Team was formed primarily of the lead authors of the 3 Decadal Survey white papers that were used to define CLARREO along with representatives of the global climate modeling community**

- **Team focused on defining a mission to fully meet the DS objectives**

Mission Science Study Organizations

- **NASA Langley Lead** (ERBE, CERES, FIRST, GIFTS, INFLAME, CALIPSO)
- **NASA GSFC** (MODIS, VIIRS, SeaWiFS, Landsat)
- **Harvard University** (INTESSA, IR benchmarking)
- **Univ. of Wisconsin** (CrIS, IASI, S-HIS, blackbodies)
- **CU-LASP** (Total and Spectral solar irradiance)
- **JPL** (AIRS, TES)
- **3 Climate Modeling Groups:**
  NCAR/DOE, NOAA/GFDL, NASA GISS
- **NIST**
- **Potential UK/NPL collaboration on solar reflectance part of CLARREO mission based on proposed TRUTHS mission.**
- **3 CLARREO relevant IIPs: LaRC, UW, LASP.**
- **1 international equivalent IIP: NPL on cooled active cavity**

Mission Science Study Accomplishments

- **First CLARREO Community Workshop held July 2007**
- **First CLARREO Team Meeting held April 30 - May 2 in Newport News, VA**
  - Reached team-wide consensus on highest level science objectives
- **Second CLARREO Community Workshop held October 2008**
  - Presented results from on-going science trade studies and Instrument Incubator projects for community comment
  - Clarification of the key science objectives
  - General consensus concerning CLARREO's role
    - Represents the beginning of a true climate observing system
    - CLARREO complements (does not replace) process missions
  - Draft Workshop Report completed
- **Solar instrument science team meeting held January 2009**
  - Reviewed requirements for radiance benchmarks, intercalibration, and polarization
  - Results will be used to produce RFP on solar instrument concepts
- **Second Team meeting scheduled for April 2009 to confirm science requirements**
- **Presentations at IGARSS, SPIE, CALCON, AMS, and a 51-paper AGU session**
- **Presentations from all meetings available on CLARREO web site**

Mission Science Measurement Objectives

- **CLARREO provides the S.I. traceable absolute accuracy in infrared and solar reflected spectra and GPS radio occultation refractivities needed to observe decadal climate change and test and improve climate predictions.**

- **The CLARREO full spectra will extend and expand the information content to a wide range of climate variables at climate change accuracy.**

- **CLARREO anchors the research and operational solar and infrared sensors at climate change accuracy through inter-calibration, providing the first "NIST in Orbit".**

- **CLARREO provides the first full infrared (IR) spectra by including the far-IR which is half of the Earth's emitted radiation, and the bulk of the water vapor greenhouse effect.**

Integrated Mission Design

- Initial Integrated Mission Design Study (December 2008)
  - Develop spacecraft sizing, cost estimates and operational concepts that cover the current mission trade space.
  - Generate mass, power and cost data in order to support key decision points necessary to define a baseline CLARREO mission concept.
  - *Develop operational scenarios to identify number of satellites required to meet the accuracy goals.*
  - Document trade studies, potential instrument technology readiness issues and mission issues.
  - Identify required mission trade studies.

- Integrated Mission Design Study Results
  - 32 payload/spacecraft/launch options were analyzed
  - Identified major cost drivers
  - Developed preliminary launch vehicle and spacecraft sizes
  - Solid preparation for mission design trades and architecture studies

Mission Design Status

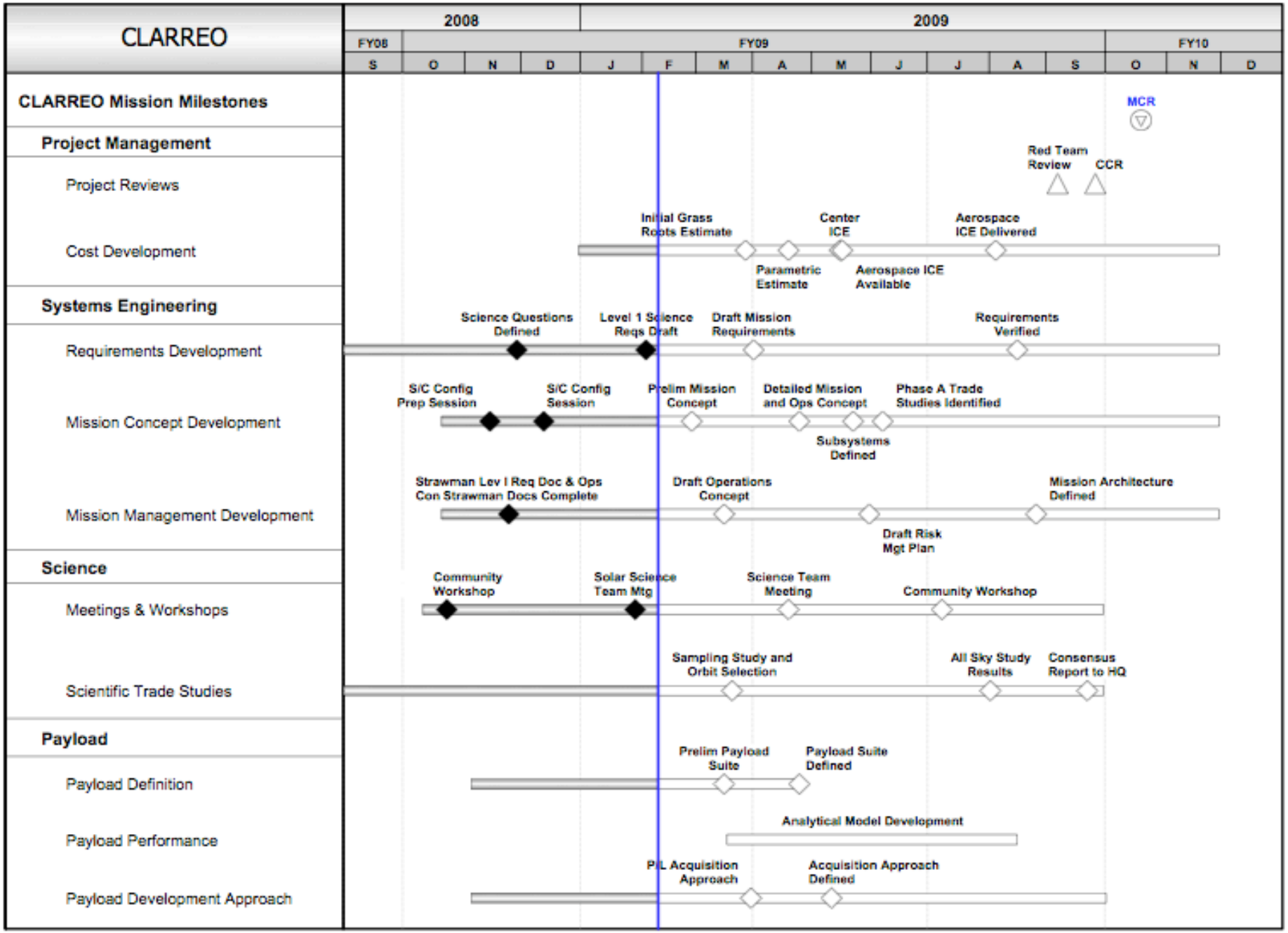
- **Results allowed us to narrow the trade space to 3 likely mission implementations**
  - More detailed engineering analysis underway
  - Used with science trade study results to select baseline mission for MCR
- **Worked with Mission Scientist to define specific configurations to deliver required accuracy, sampling and information content**
- **To meet all DS Survey objectives the mission elements required:**
  - 2-3 launch vehicles, Taurus meets all needs
  - 2-3 spacecraft, RSDO capability sufficient
  - Payload could consist of 14 instruments
  - Ground stations currently available are sufficient
  - All orbits are polar or highly inclined
- **Currently working to achieve a design that minimizes cost and complexity**

Technical challenges

- **SI traceable calibration plan from lab to orbit**
  - Develop radiometric error budget to identify instrument engineering challenges
- **Appropriate on-orbit calibration blackbodies**
  - On-orbit calibration system key to achieving required accuracy
- **Far-IR beamsplitter and detector**
  - IR detector elements sensitive from 15 to 50 μm that do not require cryogenic cooling
  - SI traceable blackbody radiance standards for wavelengths beyond 15 μm
  - Robust beamsplitters with continuous high-efficiency over the full 5-50 μm
- **Solar**
  - Enable on-orbit end-to-end spatial/spectral imager radiometric calibrations and degradation tracking with 0.3% SI traceable accuracy

Mission Formulation Manager: Stephen Sandford

February 10, 2009



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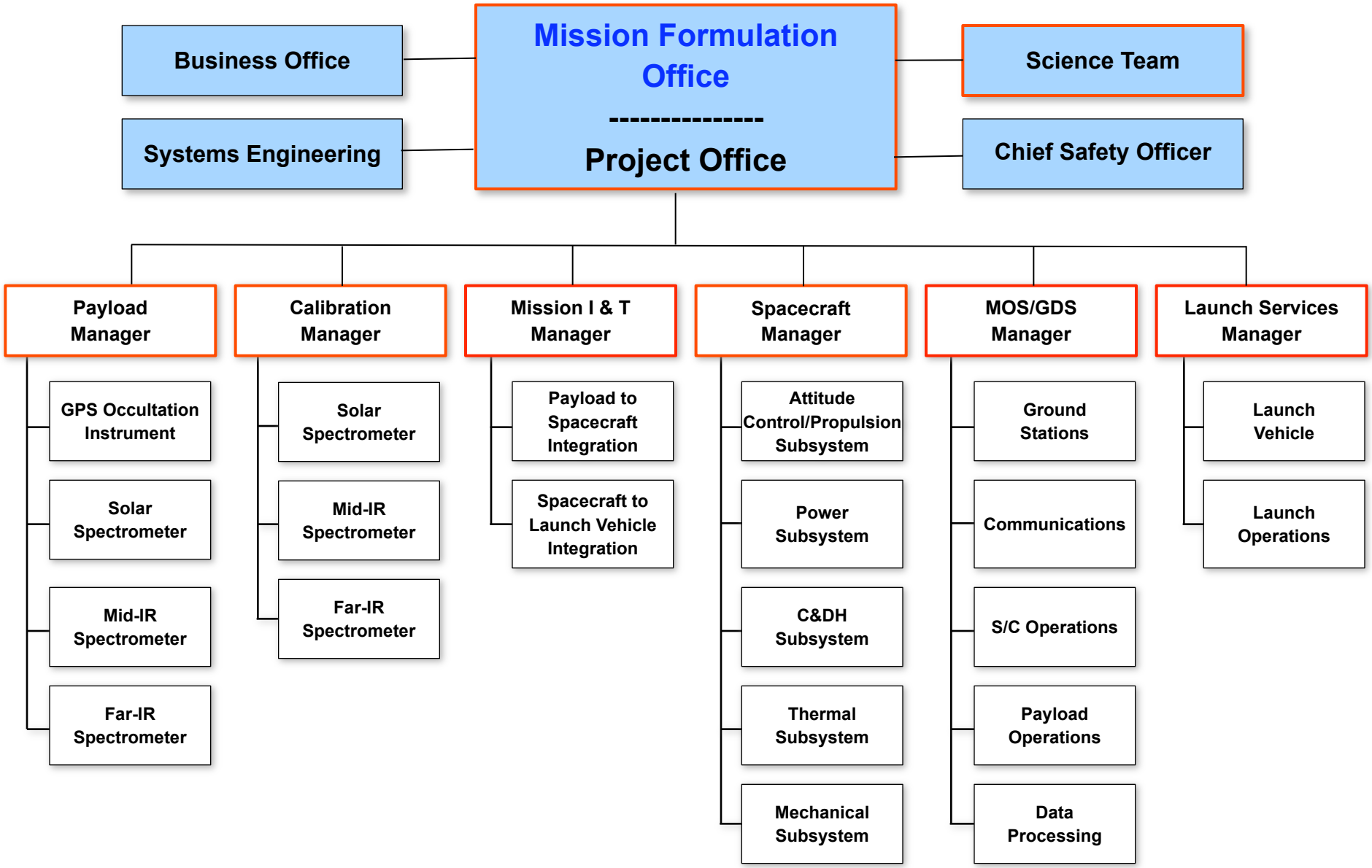
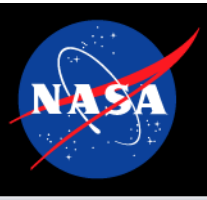
Mission Implementation





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Workforce and Budget Phasing

Workforce							
FTE	**Oct**	**Nov**	**Dec**	**2Q**	**3Q**	**4Q**	**Totals**
PM	1.0	1.4	1.4	1.3	1.3	1.3	1.3
SE	3.0	3.3	3.3	3.7	3.7	3.7	3.6
Science	4.0	5.0	4.2	4.2	4.2	4.2	4.4
Engineering	5.5	6.8	7.3	6.8	4.2	3.9	5.5
S/T FTE	**13.5**	**16.5**	**16.2**	**16.0**	**13.4**	**13.1**	**14.3**
WYE	**Oct**	**Nov**	**Dec**	**2Q**	**3Q**	**4Q**	**Totals**
PM Support	1.0	1.5	2.0	2.0	2.0	2.0	1.9
SE Support	0.5	1.0	1.0	1.0	1.0	1.0	0.9
Sci. Support	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Eng. Support	1.0	1.8	5.5	5.3	5.3	4.5	4.5
S/T WYE	**6.3**	**8.1**	**12.3**	**12.1**	**12.1**	**11.3**	**11.1**
Total Workforce:	**19.8**	**24.6**	**28.5**	**28.1**	**25.5**	**24.4**	**25.4**
Budget ($K)							
PY09 Obligations	**Oct**	**Nov**	**Dec**	**2Q**	**3Q**	**4Q**	**Totals**
FTE	123.4	207.3	217.6	645.7	536.1	523.2	**2,253.3**
WYE	120.0	0.0	1,068.1	367.0	369.1	51.0	**1,975.2**
Science/Grants	0.0	0.0	0.0	1,058.8	0.0	0.0	**1,058.8**
Other Procurement	0.0	0.0	72.9	68.2	205.0	100.0	**446.1**
HQ Funded	431.2	0.0	0.0	249.4	0.0	0.0	**680.6**
Travel	1.8	3.6	5.0	28.0	26.6	25.0	**90.0**
Total Obligations:	**676.4**	**210.9**	**1,363.6**	**2,417.1**	**1,136.8**	**699.2**	**6,504.0**

Program Integration Items for Discussion

- **NIST**
  - Calibration is critical for all DS missions
- **Launch vehicle selection**
- **Science team solicitation**
- **Data Processing and Archive Infrastructure**
- **International partnering**
- **Decadal climate change observations**
  - Agency responsibilities and accounting of costs
  - Relation of observing system with climate modeling
  - CLARREO and what else?
  - GPSRO is crucial
  - Aerosol polarimetry data continuity between Glory and ACE

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Climate Absolute Radiance and Refractivity Observatory (CLARREO)

Mission Science

- CLARREO provides the S.I. traceable absolute accuracy in infrared and solar reflected spectra needed to observe decadal climate change and verify climate predictions.
- The CLARREO full spectra will extend and expand the information content to a wide range of climate variables at climate change accuracy.
- CLARREO anchors the research and operational solar and infrared sensors at climate change accuracy through inter-calibration, providing the first "NIST in Orbit".
- CLARREO provides the first full infrared (IR) spectra by including the far-IR which is half of the Earth's emitted radiation, and the bulk of the water vapor greenhouse effect.
- CLARREO provides the first full solar reflected spectra from the Earth at climate change accuracy.

How Does CLARREO Deliver?

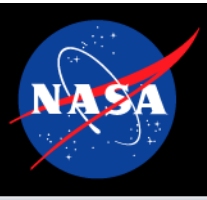
- Sacrifice spatial resolution and coverage (nadir, 100-km fov) to enable reduced instrument mass, longer dwell times, smaller optics, and higher accuracy than other spectrometers like AIRS or CrIS or SCHIAMACHY.
- Improve calibration accuracy by a factor of 2 to 3 in the infrared spectrum and a factor of 10 in the solar reflected spectrum. Accuracy requirements designed for decadal change signals.
- Select orbits and field of view so CLARREO can provide direct spectral radiance benchmarks for decadal climate change, especially infrared spectra.
- Select orbits and instrument pointing, spectral resolution, spectral coverage in order to assure that CLARREO can calibrate other solar & infrared sensors in leo and geo orbits.

Defining CLARREO

- The study plan represents an integrated strategy that engages climate scientists, modelers, satellite instrument teams and calibration experts from:
  - NASA LaRC (lead), GSFC, and JPL
  - U.C. Berkeley / GISS / GFDL
  - Harvard University
  - University of Wisconsin-Madison
  - Laboratory for Atmospheric and Space Physics
  - Contributing, but not funded:
    - National Institute of Standards and Technology
- 3 CLARREO relevant IIPs: LaRC, UW, LASP
- Potential UK/NPL collaboration on solar reflectance part of CLARREO

Goals of FY08 - FY09 Studies

- Clarify mission requirements to ensure not only climate science, but also that NASA's performance objectives are met, future costs are contained, and delays are minimized.
- Respond to several key areas of concern
  - Clearer definition of science requirements
  - Greater involvement of the climate modeling community
  - More rigorous and detailed analysis of projected costs
  - Deeper understanding of the trade space of science value/cost
- Working towards a potential Mission Concept Review in late FY09 / early FY10.



CLARREO POCs and Website

- **Program Scientist** **Don Anderson** **HQ**
- **Program Executive** **Richard Slonaker** **HQ**
- **Mission Scientist** **Bruce Wielicki** **LaRC**
- **Mission Formulation Manager** **Stephen Sandford** **LaRC**
- **Mission Formulation Science Lead** **David Young** **LaRC**
- **Mission Chief Engineer** **Mike Gazarik** **LaRC**

- **Website:** **http://clarreo.larc.nasa.gov/**

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Thank You

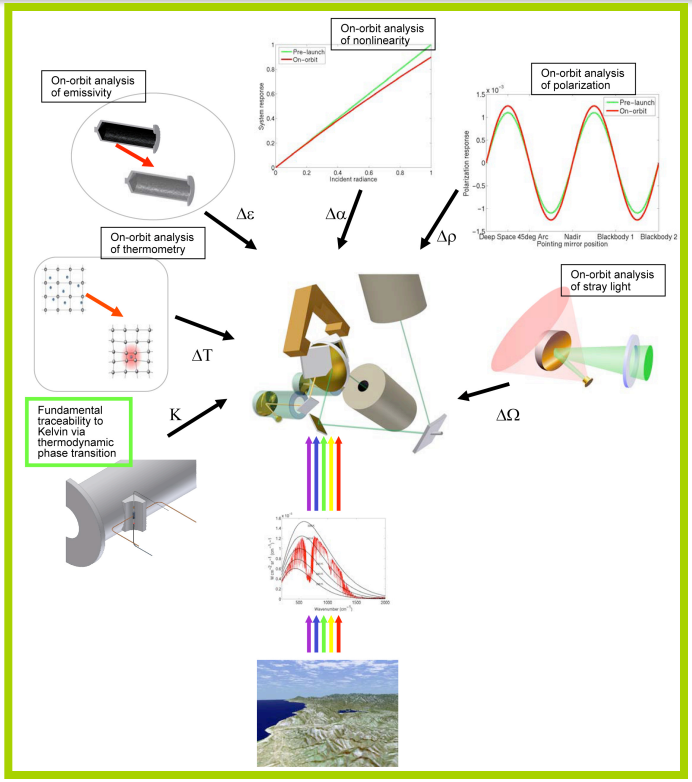
Baseline Mission from the Decadal Survey

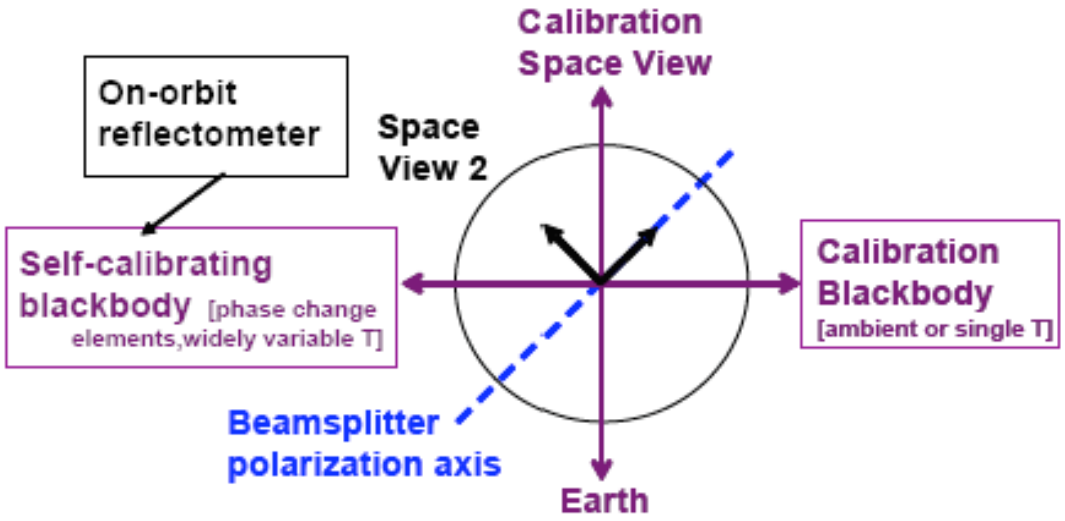
- **Three satellites in 90° orbits to provide accurate temporal sampling**
- **Instruments**
  - **Redundant hyperspectral IR spectrometers** on each satellite
    - 200 - 2000 cm-1 with 1 cm-1 resolution
    - Nadir viewing with ~100 km FOV
    - Accuracy goal: 0.1 K (3 σ)
  - **Hyperspectral solar spectrometers** on third satellite
    - 300 - 2000 nm with 15 nm resolution
    - Accuracy goal: 3 parts per 1000
  - **GPS radio occultation receivers** on each satellite

- ***This is the starting baseline, but we are now working to provide a much more rigorous determination of CLARREO requirements***

Key Elements of the CLARREO Mission

Calibration is the Foundation of CLARREO

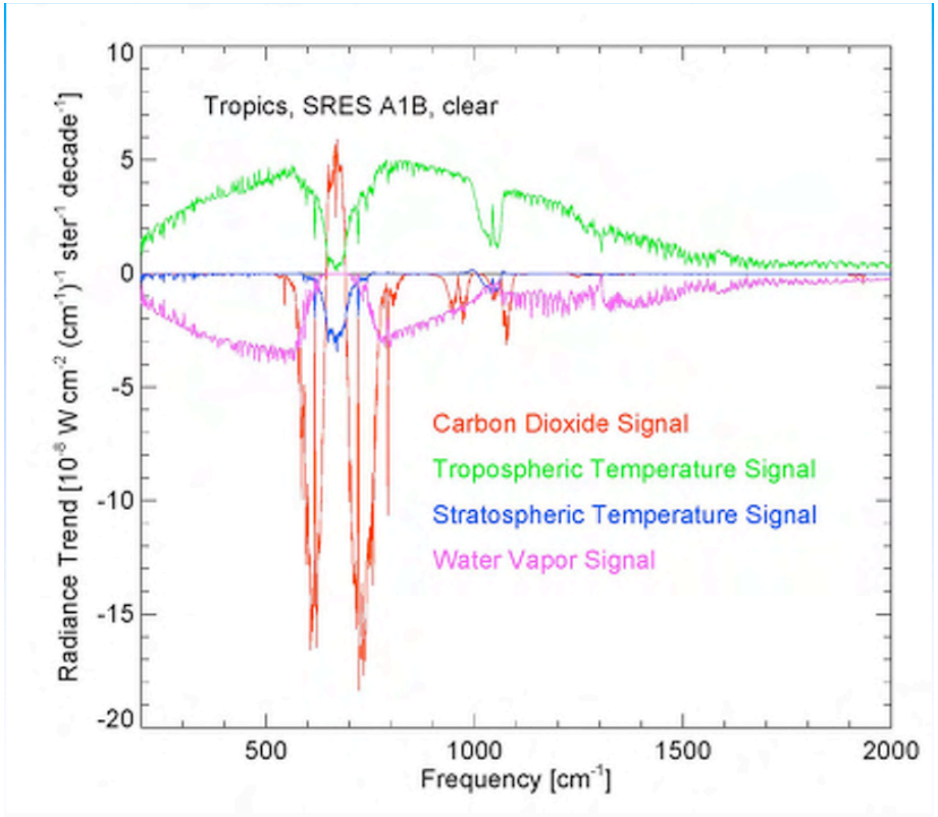


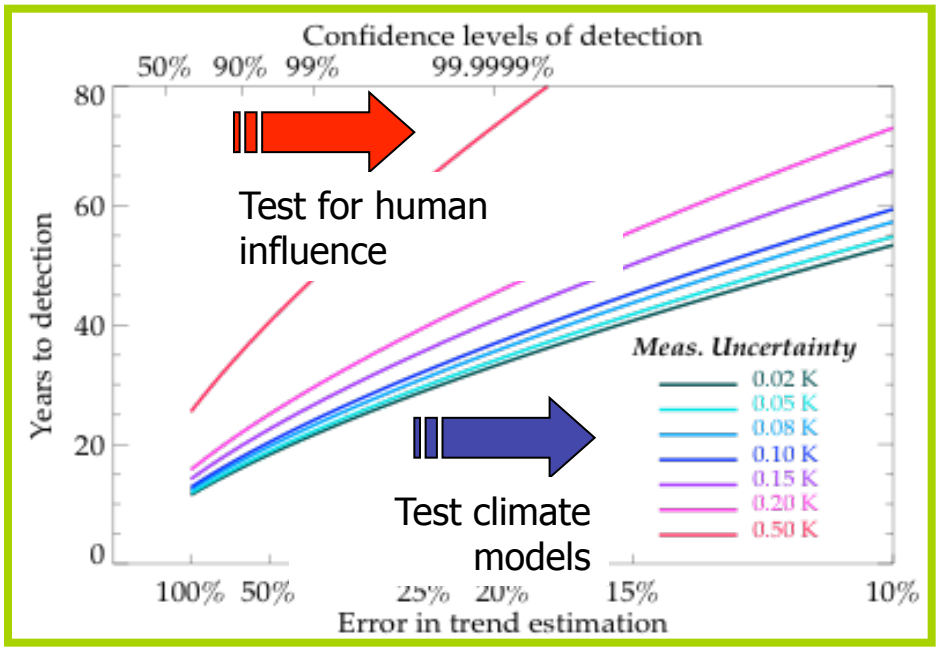


Dykema et. al. 2008

- **CLARREO requires complete calibration traceability during all phases of development through operations on orbit**
- **Demonstrating on-orbit traceability will impact the accuracy of all future climate sensors**
  - **Technology can be incorporated into future designs**
  - **Operational sensors can be designed to make optimal use of CLARREO intercalibration**

CLARREO Enables Climate Trend Detection



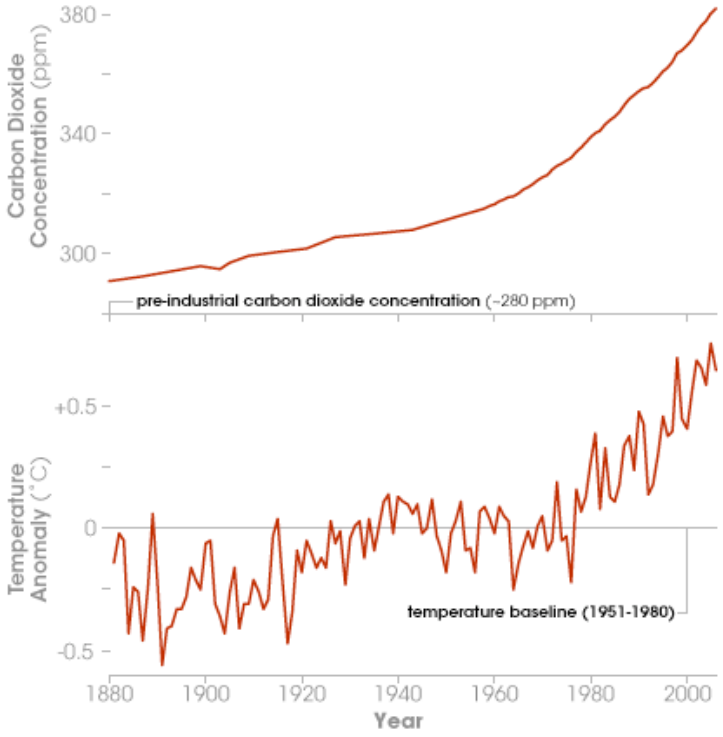


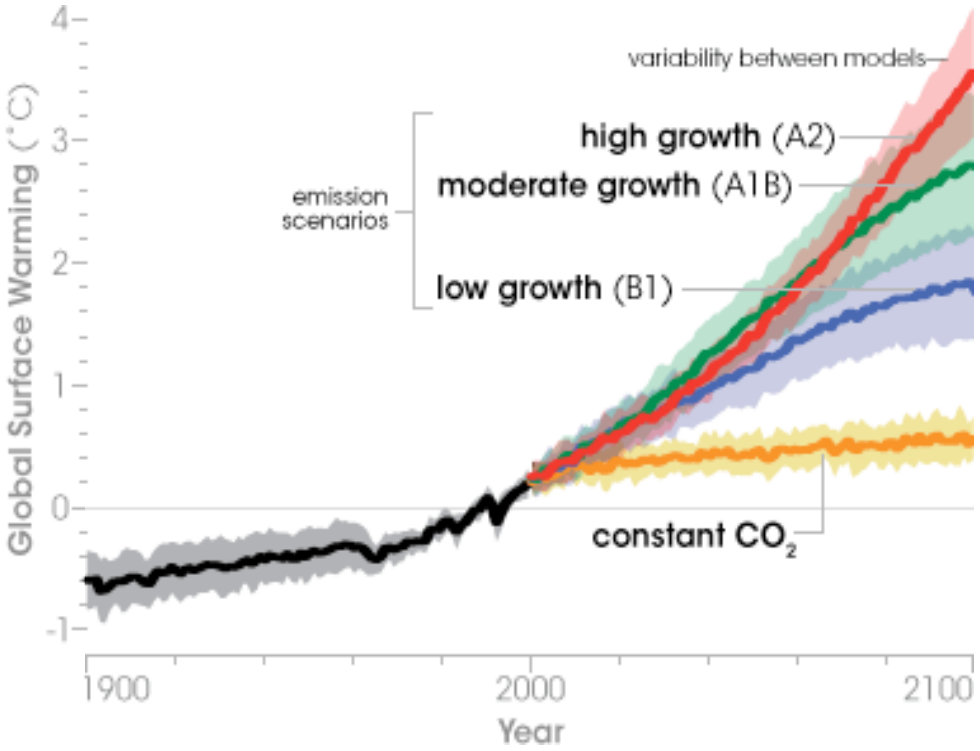
Temperature Trends: Error vs. Detection

Anderson et. al. 2007

- **CLARREO will provide spectral radiances and refractivities of sufficient accuracy to detect decadal scale climate trends**
- **The documented, verifiable accuracy of the CLARREO data record will enable trend detection with a shorter time record**
- **Unscrambling the trends has been demonstrated for clear-sky IR and GPS**

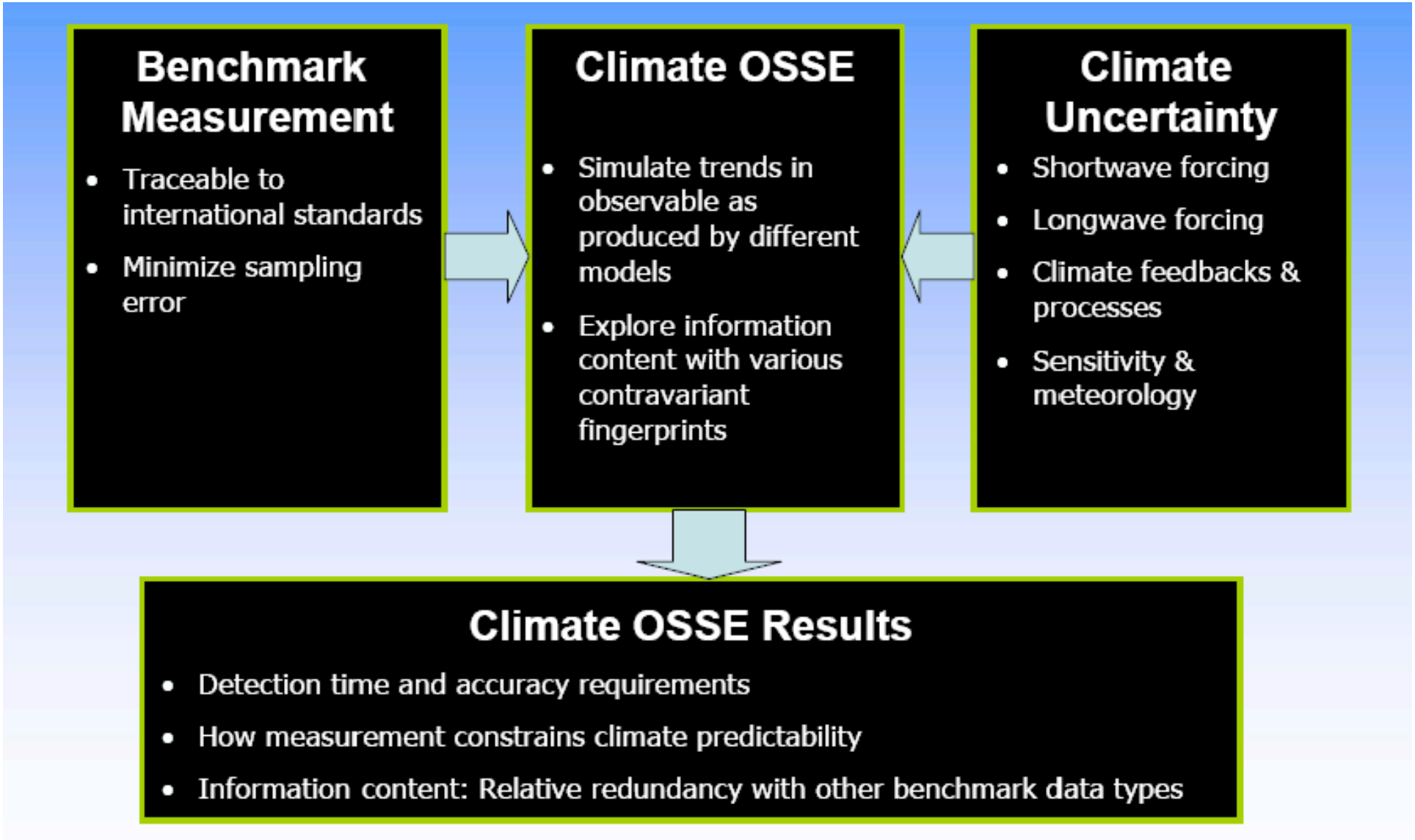
CLARREO Reduces Climate Model Uncertainty





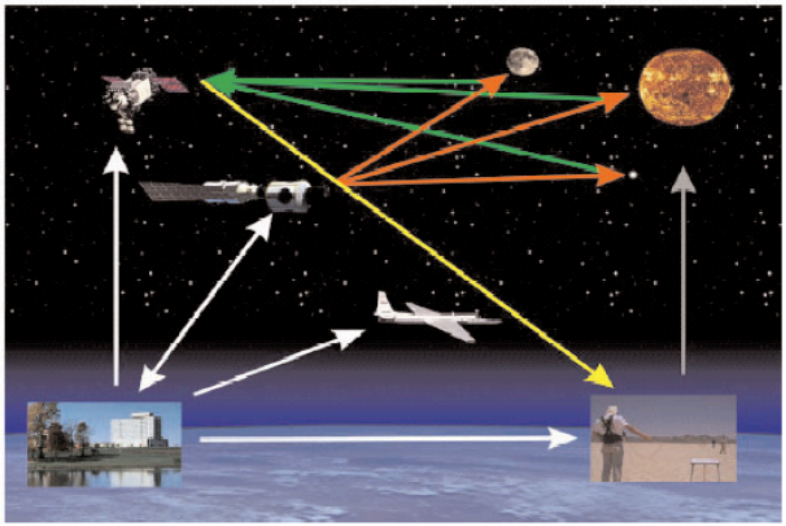
- **The range of estimates of climate sensitivity arises from uncertainties in the climate models and their internal feedbacks, particularly those related to clouds and related processes. (Excerpted from IPCC 2007)**
- **CLARREO data will be used to test the realistic range of climate predictions**
- **Reducing the range of future scenarios will enable more informed decisions concerning mitigation and adaptation**

Improvement and Validation of Climate Models



CLARREO and Intercalibration

Future: All measurements for Global Climate Change verifiably traceable to SI Units through NMIs



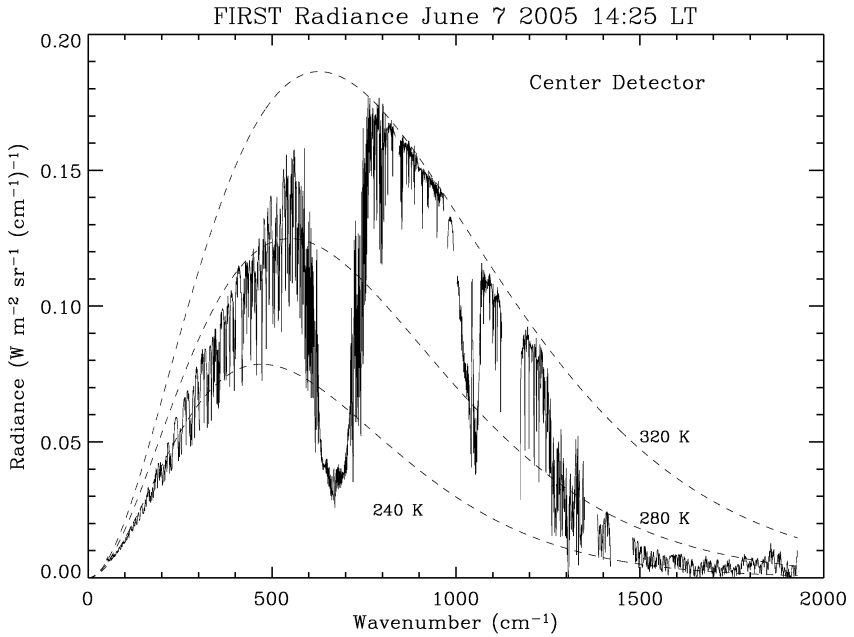
… to ensure that instrument calibrations are accurate, traceable throughout the world, and maintained in a historical record.

National Institute of Standards and Technology NIST

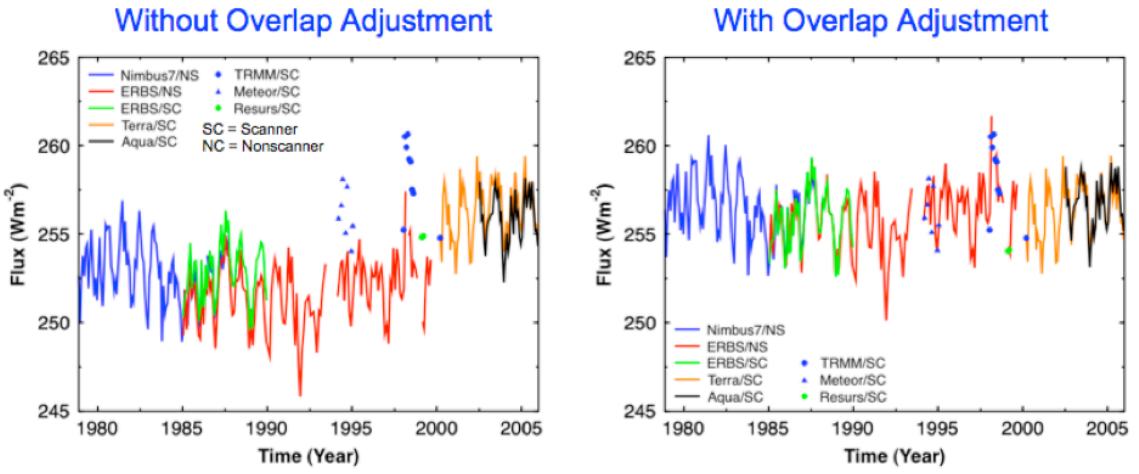
- **CLARREO will provide a calibration source for the Earth observing system**
- **Calibration requirements for climate addressed by several international organizations:**
  - **Global Climate Observing System (GCOS)**
  - **Achieving Satellite Instrument Calibration for Climate Change (ASIC^3)**
  - **Global Spacebased Inter-Calibration System (GSICS)**
  - **CEOS Working Group on Calibration / Validation**

Additional CLARREO Benefits

- **Provide the first space-based measurements of the Earth's far infrared spectrum which is half of the cooling to space and the majority of the water vapor greenhouse.**



- **Dramatically reduce the effects of climate record data gaps**



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CLARREO Science Workshop

Summary

- **Held October 21-23, 2008 in Washington DC**
- **Focus of presentations was on Pre-Phase A work**
  - Also 21 contributed posters from the broader community
- **Over 100 participants**
  - Included representatives from Academia, Industry, NASA HQ, GSFC, JPL, LaRC, NOAA, NIST, and EUMETSAT
  - Major participation by climate modeling groups
- **The meeting successfully met major objectives**
  - Presented results from on-going science trade studies and Instrument Incubator projects for community comment
  - Clarification of the key science objectives
  - General consensus concerning CLARREO's role
    - Represents the beginning of a true climate observing system
    - CLARREO complements (does not replace) process missions

Agenda

- **The Workshop was organized to focus on 5 critical aspects of CLARREO that will drive mission requirements**
  - S.I. Traceable measurements for climate benchmarking
  - CLARREO's role in climate prediction and climate model testing
  - Temporal and spatial sampling requirements
  - Applied S.I. traceability (and Instrument Incubator Proposals)
  - Inter-calibration of operational instruments using CLARREO
- **Plans and initial results of specific Pre-Phase A studies targeting these areas were presented and discussed**
- **Additional presentations from NASA HQ, NOAA, NIST, and the Earth Systematic Mission Program Office**

Remaining Challenges

- **Science Questions finalization and prioritization**
  - Working to clearly state the unique aspect of CLARREO relative to the existing and planned climate observing system
- **Answering key questions**
  - Temporal and Spatial Sampling
    - Are accuracy goals based on global, zonal, or regional means?
    - What are the optimal temporal sampling for both IR and solar?
  - Solar portion of CLARREO
    - What constitutes a reflected solar benchmark?
    - How to ensure accurate intercalibration in the solar?
- **Incorporating Climate Observing System Simulation results into mission planning**

Steps Towards Mission Concept Review

- **Begin new studies focused on identified issues**
  - Mission studies will continue through 2009.
- **Finalize Science Requirements**
  - Using input from this workshop the team will produce a final version of the Science Objectives document by November 30
  - Develop draft Level 1 requirements with some basic trades:
    - Feb: Develop several mission concepts based on these requirements/ trades
    - March: Produce initial cost scenarios for assistance in cost/science prioritization at April team meeting
  - April team meeting for agreement on Level 1 requirements
  - Plan for MCR in September/October 2009

Planning for CLARREO: Goals of FY08 - FY09 Studies

- **Clarify mission requirements to ensure not only climate science, but also that NASA's performance objectives are met, future costs are contained, and delays are minimized.**
- **Respond to several key areas of concern**
  - Clearer definition of science requirements
  - Involvement of the climate modeling community that it is intended to serve.
  - Improve the accuracy of cost estimates
  - Deeper understanding of the trade space of science value/cost
- **Working towards a potential Mission Concept Review in late FY09 / early FY10.**
- **Earliest possible launch within current budget is 2017, but 2015 is achievable with more rapid ramp up.**

CLARREO Science Questions

- **CLARREO can address climate science questions using these three methodologies:**
  - **Questions that CLARREO will address directly with current technology and without the need for any other observations: primarily mid-infrared spectra.**
  - **Questions that CLARREO will address directly with expected definition study and IIP confirmation of recent advances in metrological technology and sampling strategies: primarily solar and far-infrared spectra.**
  - **Questions that CLARREO will address in combination with other satellite solar and infrared sensors: mid-IR, far-IR, and solar spectra**
- **Defining what CLARREO is and what it is not**
  - ***Not a replacement for process missions***
  - ***Not a replacement for operational sounders***
  - ***NASA portion of CLARREO is complementary to continuity of TSIS and CERES measurements (NOAA part of CLARREO).***

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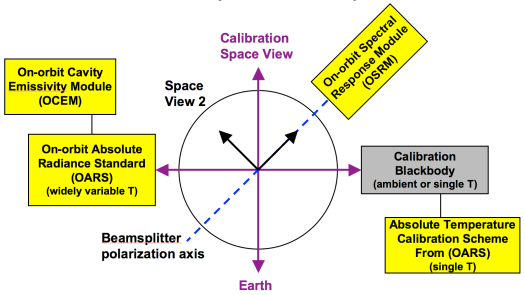
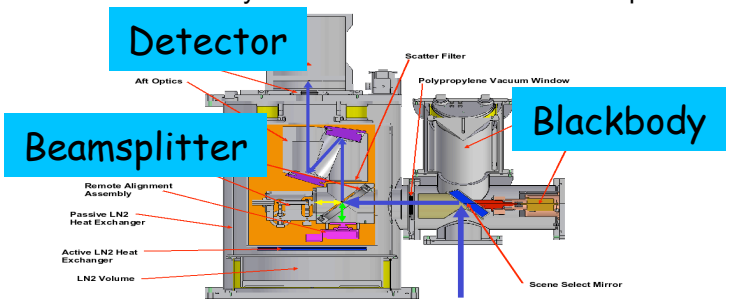
CLARREO Technology Investments

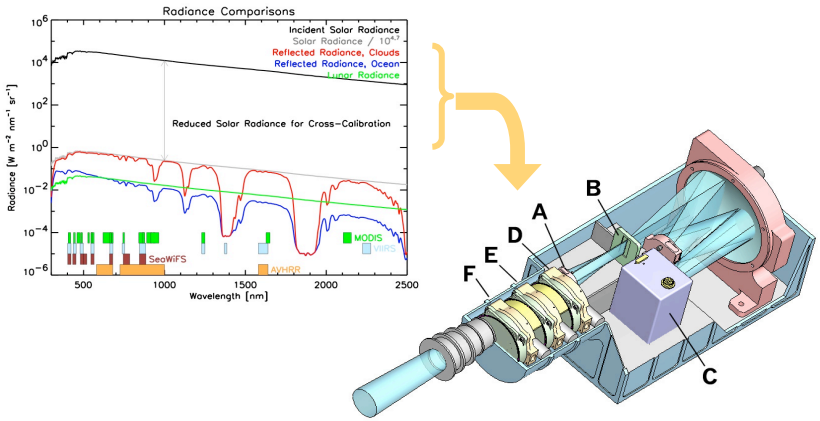
- **A New Class of Advanced Accuracy Satellite Instrumentation (AASI) for the CLARREO Mission (Wisconsin / Harvard)**
  - Develop and demonstrate key technologies necessary to measure IR spectrally resolved radiances with ultra-high accuracy (<0.1 K 3 sigma) brightness temperature (at scene temperature) for CLARREO.
  - Technologies include:
    - On-orbit Absolute Radiance Standard including Miniature Phase Change Cells
    - On-orbit Cavity Emissivity Module using quantum cascade laser (QCL) and heated halo reflection
    - On-orbit Spectral Response Module using QCL



- **CORSAIR: Calibrated Observations of Radiance Spectra from the Atmosphere in the far-InfraRed (NASA Langley)**
  - Performance goals are 0.1 Kelvin absolute radiometric accuracy (3 standard deviations) over a spectral range from 200 to 2000 cm^{-1} with a resolution of 1.0 cm^{-1}.
  - Technologies include
    - IR detector elements sensitive from 15 to 50 μm that do not require cryogenic cooling
    - SI traceable blackbody radiance standards for wavelengths beyond 15 μm
    - Robust optical beamsplitters with continuous high efficiency over the full 200 to 2000 cm^{-1} spectral range



- **A Hyperspectral Imager to Meet CLARREO Goals of High Absolute Accuracy and On-Orbit SI Traceability (LASP)**
  - Improve radiometric accuracy of visible & Near-Infrared hyperspectral imaging needed for Earth climate studies via cross-calibrations from spectral solar irradiances.
  - Enable on-orbit end-to-end spatial/spectral imager radiometric calibrations and degradation tracking with 0.2% SI-traceable accuracy



Partnering

- **NIST**
  - A high level agreement with NIST is a necessity for CLARREO
    - This was done on EOS to ensure their involvement
    - Working with EOS Project Scientist and ESM-PO
  - Calibration is essential: we can leverage their existing facilities
    - NASA investment may be needed to augment capabilities
      - Far more cost-effective than recreating capabilities
      - NIST **will** partner in a cost-sharing mode
  - This needs to be handled at a high level so that we can coordinate
    - If there is an AO/NRA for instruments, we (and NIST) do not want each bidding group to negotiate individual agreements with NIST
- **UK**
  - Developing a package for HQ to use in partnering discussions with the UK
  - TRUTHS concept a potential solution for reflected solar portion of CLARREO

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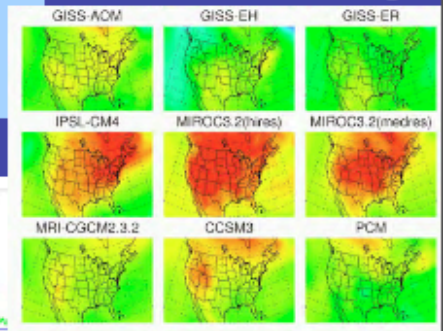
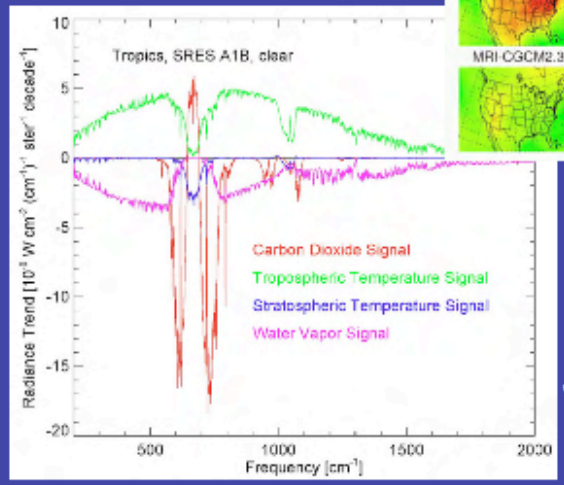
CLARREO Benchmark Radiance Climate Model OSSEs

- **CLARREO Mission Objectives include monitoring of climate change using SI-traceable spectral radiance benchmarks at high absolute accuracy**

- **Key benchmark radiance trade studies:**
  - Add CLARREO simulators to major climate models to test CLARREO decadal change spectra signals.
  - Verify accuracy of simulators using monthly mean properties versus individual time steps.

Climate Model Predicted Change





Simulate Decadal Spectral Signals

Test Climate Model Predicted Spectral Signals Against CLARREO Spectral Benchmarks

Determine Climate Model Prediction Accuracy, Needed Improvements

- **Approach**
  - Climate OSSE using CLARREO simulator in climate model for decadal change
  - NCAR, GFDL, and NASA GISS climate models key participants
  - IR clear-sky already published, IR all-sky underway, Solar is new.

- **The first use of the OSSE concept with decade to century climate models**

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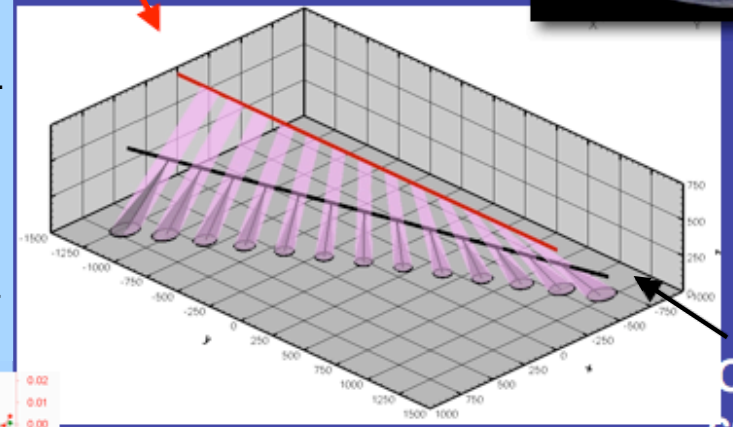
CLARREO Solar Spectral Intercalibration

- **CLARREO Mission Objectives require that climate variables remotely sensed from space using reflected solar radiation be at accuracies sufficient for detection of decadal change.**
  - Accuracy requirements for decadal change taken from previous reports
  - A potential method to achieve climate accuracy is for CLARREO to calibrate other sensors.

Climate Change

- **There are several key intercalibration studies**
  - Does spectral response of filters change enough over time to alias climate change (e.g. MODIS, VIIRS)?
  - Can CLARREO detect and correct spectral response changes of other sensors?
  - Can CLARREO achieve sufficient space-time-angle sampling for intercalibration of other sensors?

Aqua MODIS, CERES
705km orbit



CLARREO
600km orbit

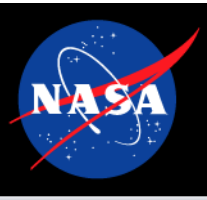
Cloud Feedback Observations

CLARREO Calibrates CERES/VIIRS

- **Three approaches**
  - Climate OSSE using CLARREO simulator in climate model for decadal change
  - Simulate MODIS and VIIRS using Schiamachy in orbit spaceborne spectrometer (< 1nm $\Delta\lambda$; 30 by 60km fov)
  - Simulate CLARREO using MODIS surface/aerosol/cloud properties + radiative transfer theory (< 1nm $\Delta\lambda$; 1km fov)

Definition Studies Underway

- **Verify IR and solar spectral benchmarking in cloudy sky conditions, determine accuracy and sampling requirements**
  - Climate OSSE groups, Harvard, LaRC, CU-LASP
- **IR and solar intercalibration space/time/angle match requirements, spectral resolution/coverage requirements**
  - LaRC, UW, GSFC, JPL
- **Role of polarization in solar benchmarking and intercalibration**
  - GISS, LaRC, GSFC, CU-LASP
- **Orbit design to optimize benchmarking and intercalibration goals: inclination, altitude, number of orbits (sampling)**
  - LaRC, Harvard, Climate OSSE groups
- **Initial results presented at October 2008 Workshop**
  - Available at clarreo.larc.nasa.gov



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Scientific Basis of CLARREO

- **CLARREO Societal Benefits**
  - **Establishing a climate benchmark:**
    - **The essential responsibility to current and future generations to put in place a benchmark climate record, global in its extent, accurate in perpetuity, tested against independent strategies that reveal systematic errors, and pinned to international standards on-orbit.**
  - **Testing climate models:**
    - **The critical need for climate forecasts that are tested and trusted through a disciplined strategy using state-of-the-art observations with mathematically rigorous techniques to systematically improve those forecasts.**
- **CLARREO Science Objectives**
  - **Archive a benchmark climate record that contains the necessary information to reliably document and detect climate trends.**
  - **Provide on-orbit SI traceable emitted infrared and solar reflected calibration to other satellite sensors.**
- **Consensus?**
  - **Yes on the need for highly accurate observations**
    - **- GSICS, GCOS, etc**
  - **Yes on the need for high accuracy climate data records**
  - **Yes on the advancements necessary to achieve SI-traceability**

What is a Climate Benchmark?

- **A climate benchmark has three primary characteristics:**
  - SI traceable calibration of its observation at the accuracy level required to detect decadal climate change in key climate variables.
  - Sampling in wavelength/space/time/angle sufficient to reduce sampling noise (random) and sampling alias (changing bias) to a level well below that of climate decadal change.
  - Information content in the observations sufficient to determine climate change in variables that the climate models have shown to be key to understanding and predicting past and future climate change.